

# **DOE Progress Review**

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## **LINAC DESIGN STATUS**

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**Oct. 31, 2000**

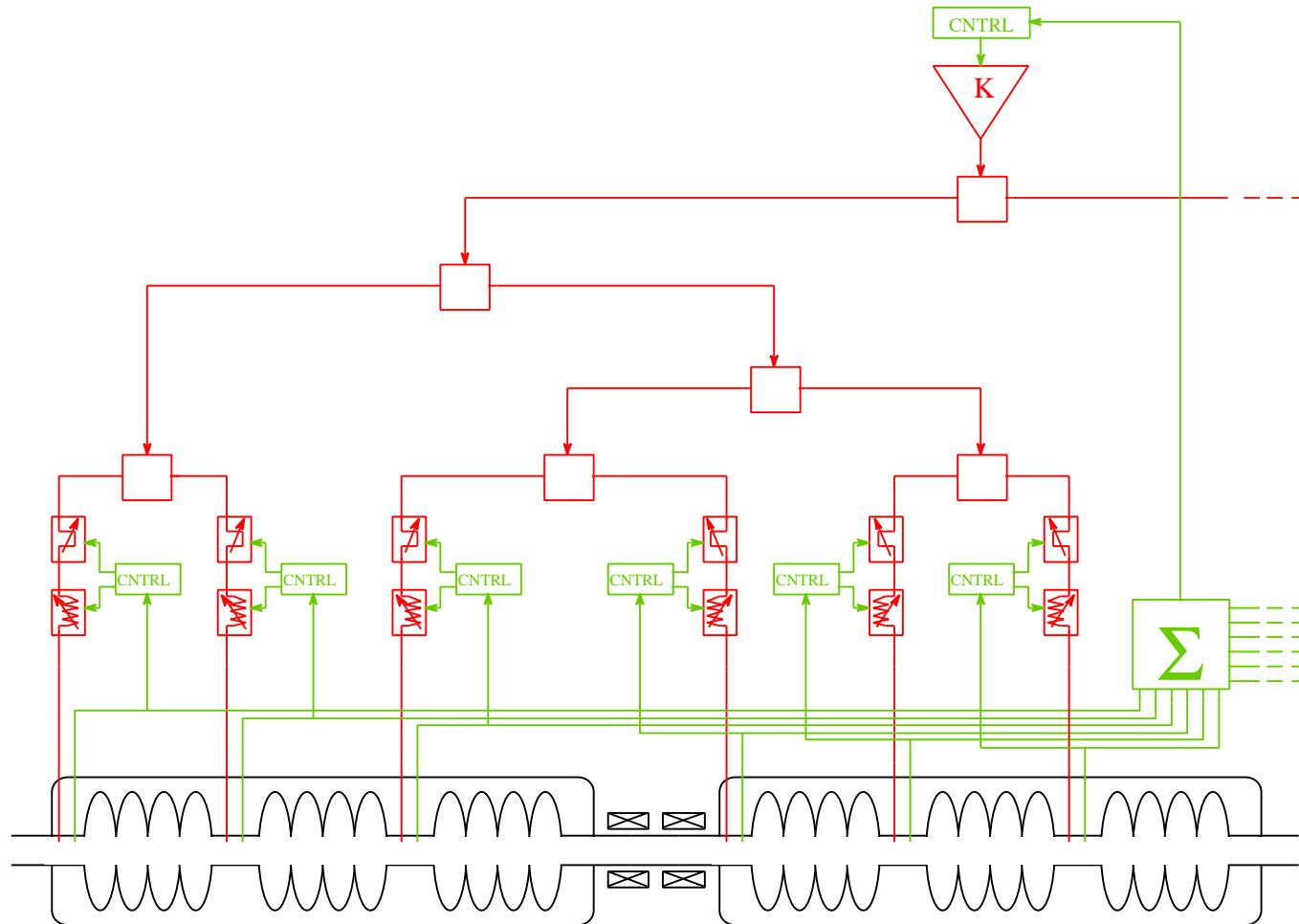
# Outline

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- SRF Linac design
- End-to-end beam dynamics simulations
- Cavity physics (Billen)
- SRF Beam commissioning (Young)

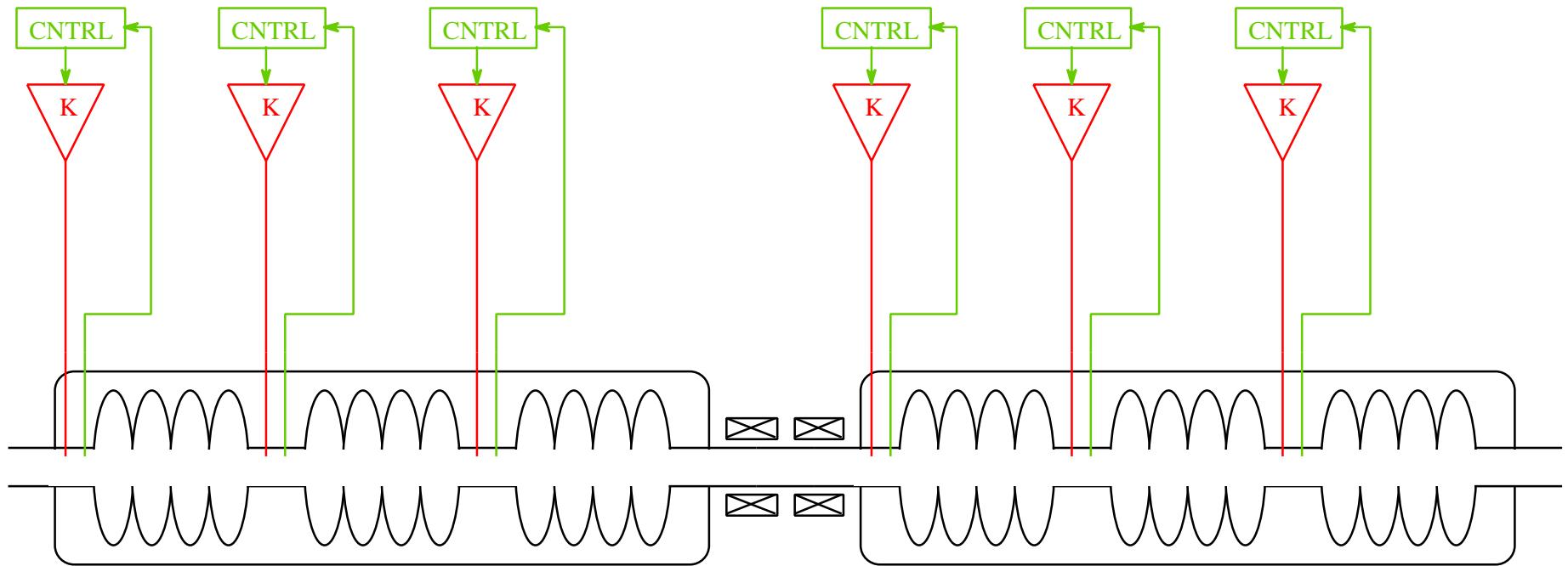
# “March” Design, 12 Cavities/klystron Individual + Collective Cavity Control



# Reference Design

## Cavity/Klystron Individual Control

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# Linac Architecture Summary



Structure	W <sub>final</sub>	Total Length	Cells per Cavity	Cavities per Module	Modules	No of Klystrons	Structure Length
	MeV	m					m
<b>DTL</b>	86.8	36.6	60 to 21		6	6	36.6
<b>CCL</b>	185.6	91.9	8	12	4	4	55.4
<b>SRF I</b>	379.2	157.7	6	3	11	33	64.2
<b>SRF II</b>	948.7	276.0	6	4	15	59	118.4
<b>SRF upgrade</b>	1227.6	323.4	6	4	6	25	47.3

Structure	HVPS	HVPS Power	Transmitters	Klystrons	Klystron Power
		MW			MW
<b>RFQ &amp; DTL</b>	3	10	7	7	2.5
<b>CCL &amp; HEBT</b>	5	10	6	6	5.0
<b>SRF I &amp; II</b>	8	10	16	92	0.55
<b>SRF upgrade</b>	3	10	5	25	0.60

# Linac Design is Mature

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- DTL Physics design is complete
  - Cavity cold-modeling underway
  - Field stabilization scheme demonstrated
- CCL Physics design is complete
  - Cavity cold-modeling underway
  - Cavity geometry finalized
    - details being incorporated into design
  - Bridge-coupler details under study
  - Hot-model in fabrication
- SRF Reference design is complete
  - Cavity layout is frozen
  - Investigating alternate phase & quad laws



# Linac Interfaces are Mature

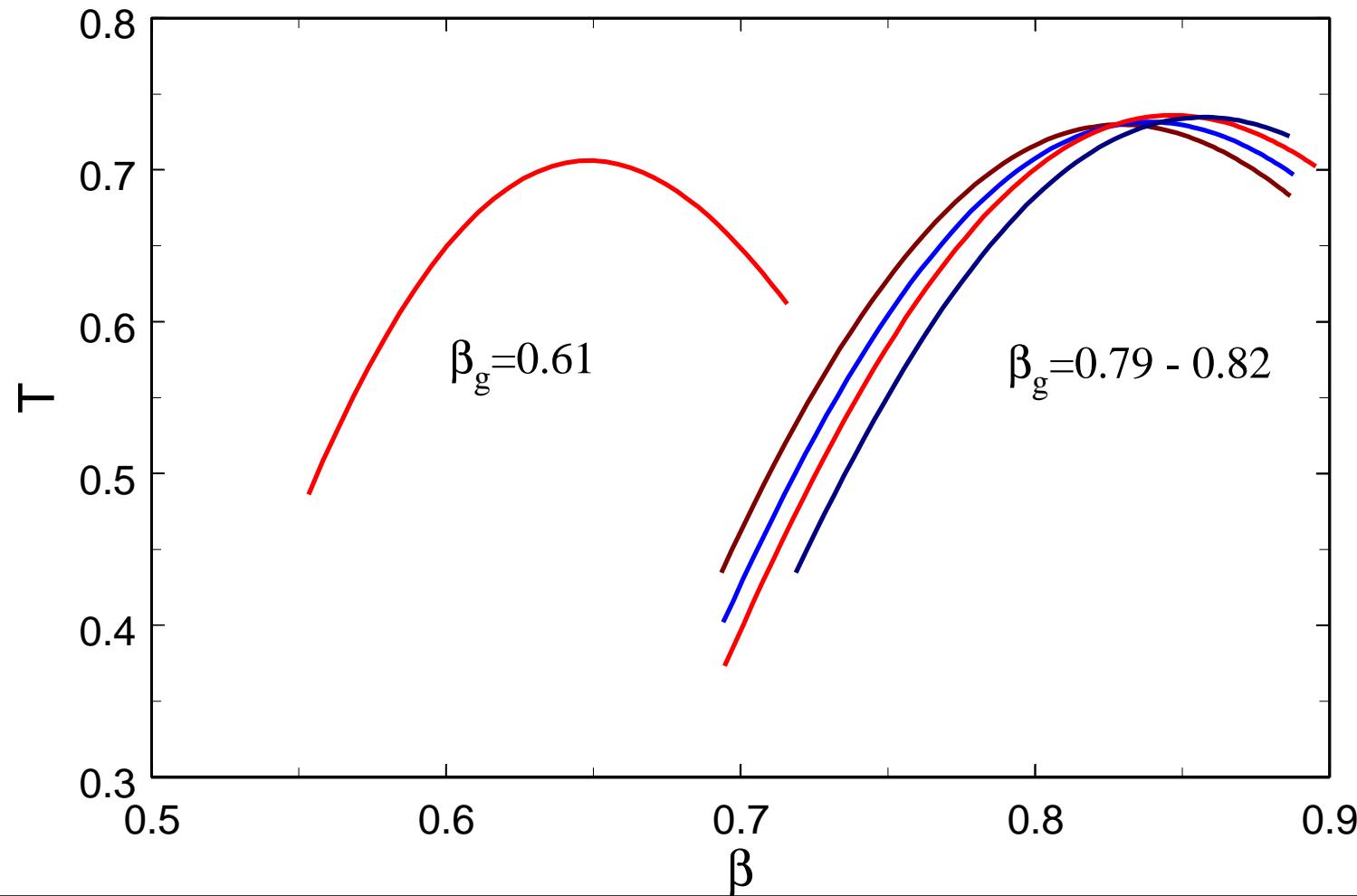
- MEBT-DTL: dimensions are frozen, matching is complete
- DTL-CCL: dimensions are frozen, matching is complete
- CCL-SRF: dimensions are frozen, have a matched solution
- SRF  $\beta_1$ - $\beta_2$ : have a matched solution
- SRF-HEBT: length frozen
  - end-to-end simulations underway
  - energy corrector/spreader cavity-physics design complete
  - HEPT interface workshop in Dec.

# SRF Design is Based on 2 Cavity bs

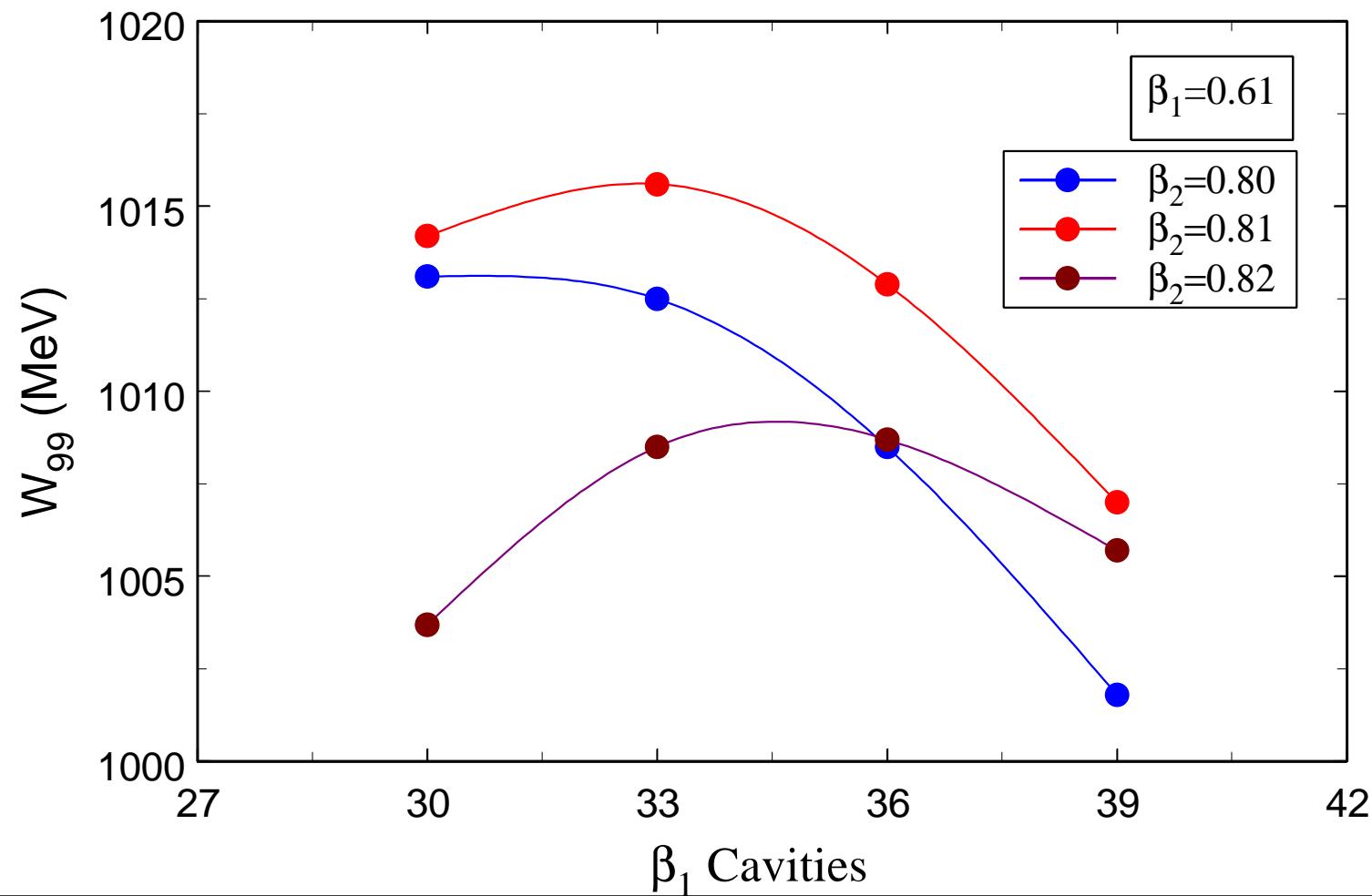


- $E_{\max} \leq 27.5 \text{ MV/m}$
- Optimized for cost with 2  $\beta$  cavities
  - a 3rd lower- $\beta$  cavity would be too numerous & inefficient
- $\beta_1 \equiv 0.61$ 
  - based on earlier 2-cavity design studies
  - 5 MW CCL modules coarsely quantize initial energy
- $0.74 \leq \beta_2 \leq 0.82$ 
  - higher  $\beta$  provides more efficient acceleration
    - i.e. higher  $E_0$ , T &  $L_{\text{cav}}$
    - if  $E_{\max} > \langle E_{\max} \rangle$ , higher  $\beta$  supports a higher  $W_{\text{final}}$
- Transition energy
  - maximized final energy for fixed cost machine

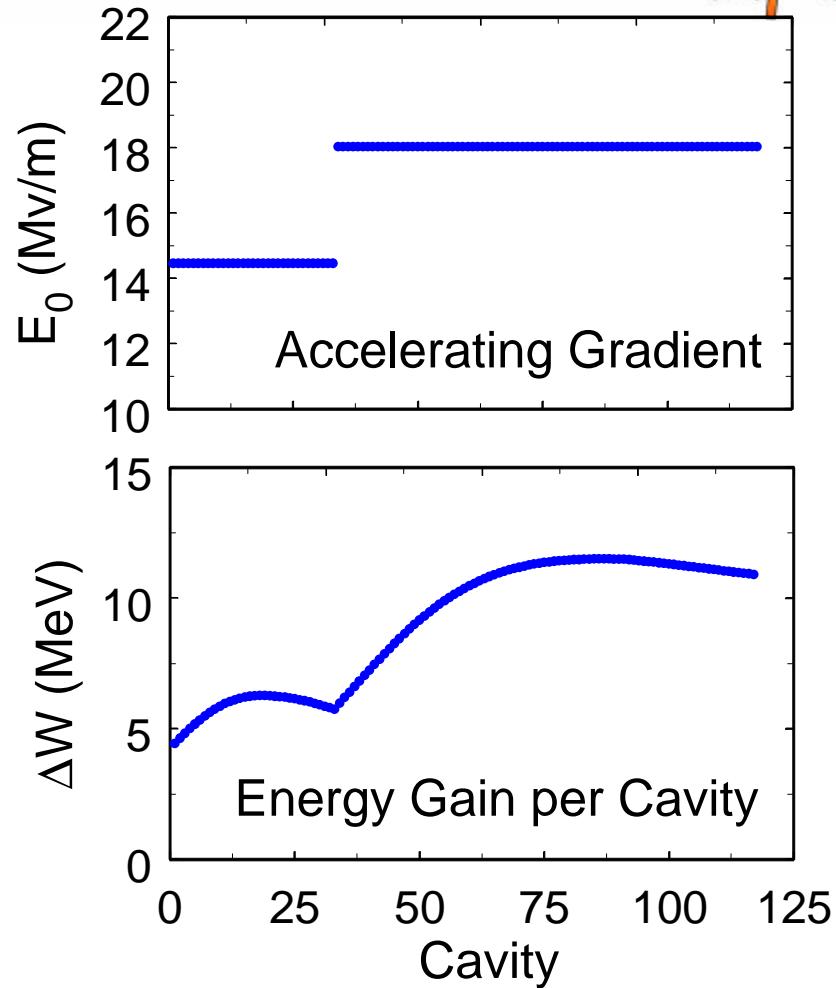
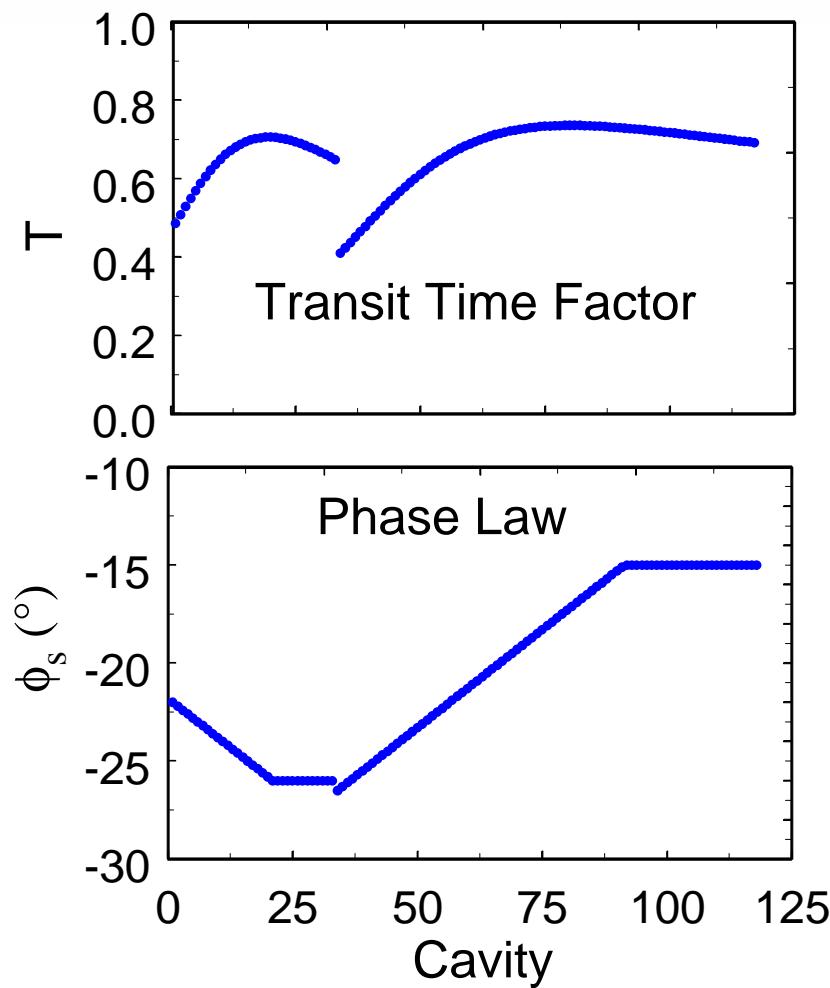
# Transit Time Factors ( $T_{ave}$ ) for Candidate Cavities Increase With $b$



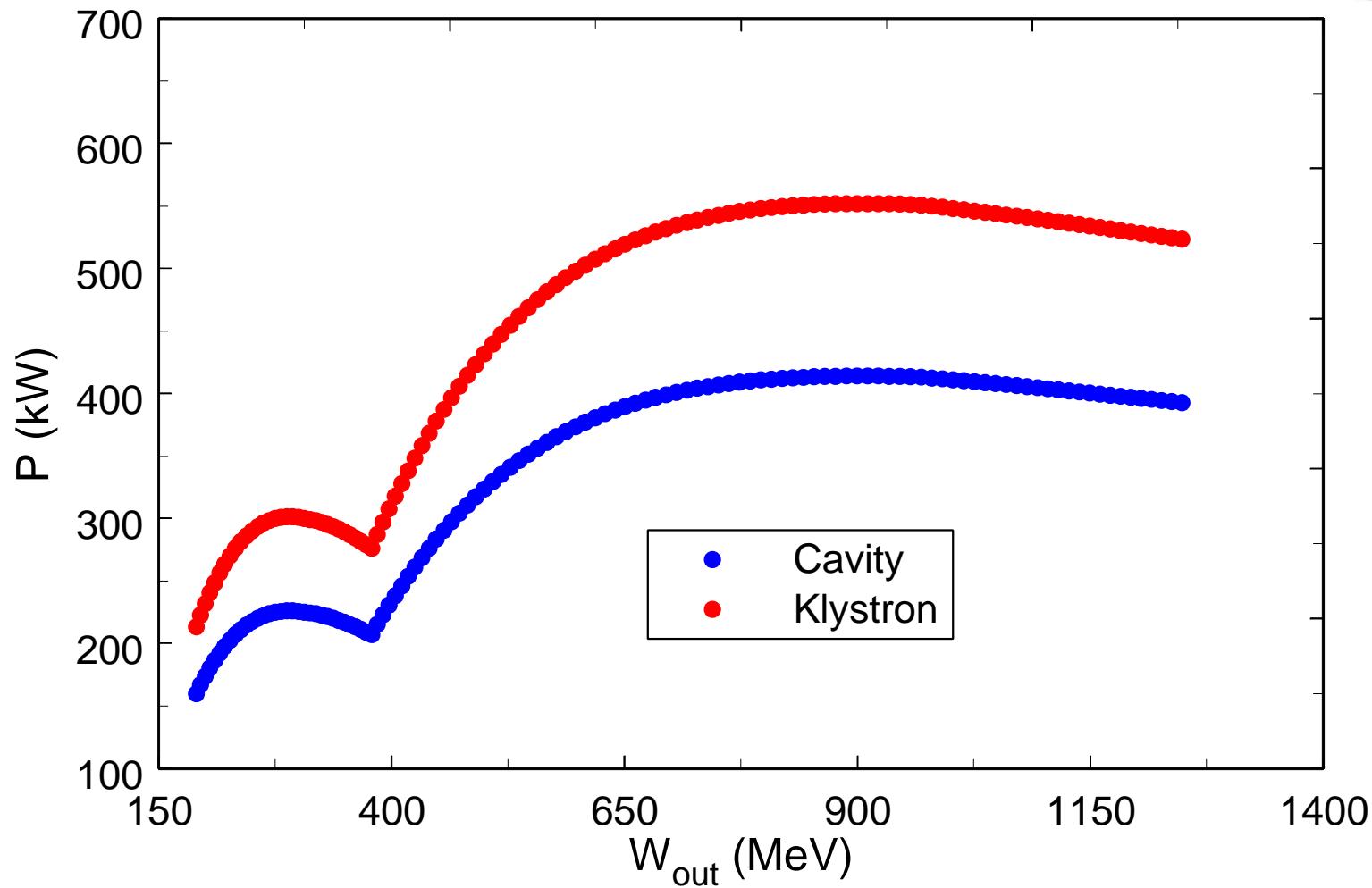
# Cavity b & Transition Optimization for a Linac Having 99 Total Cavities



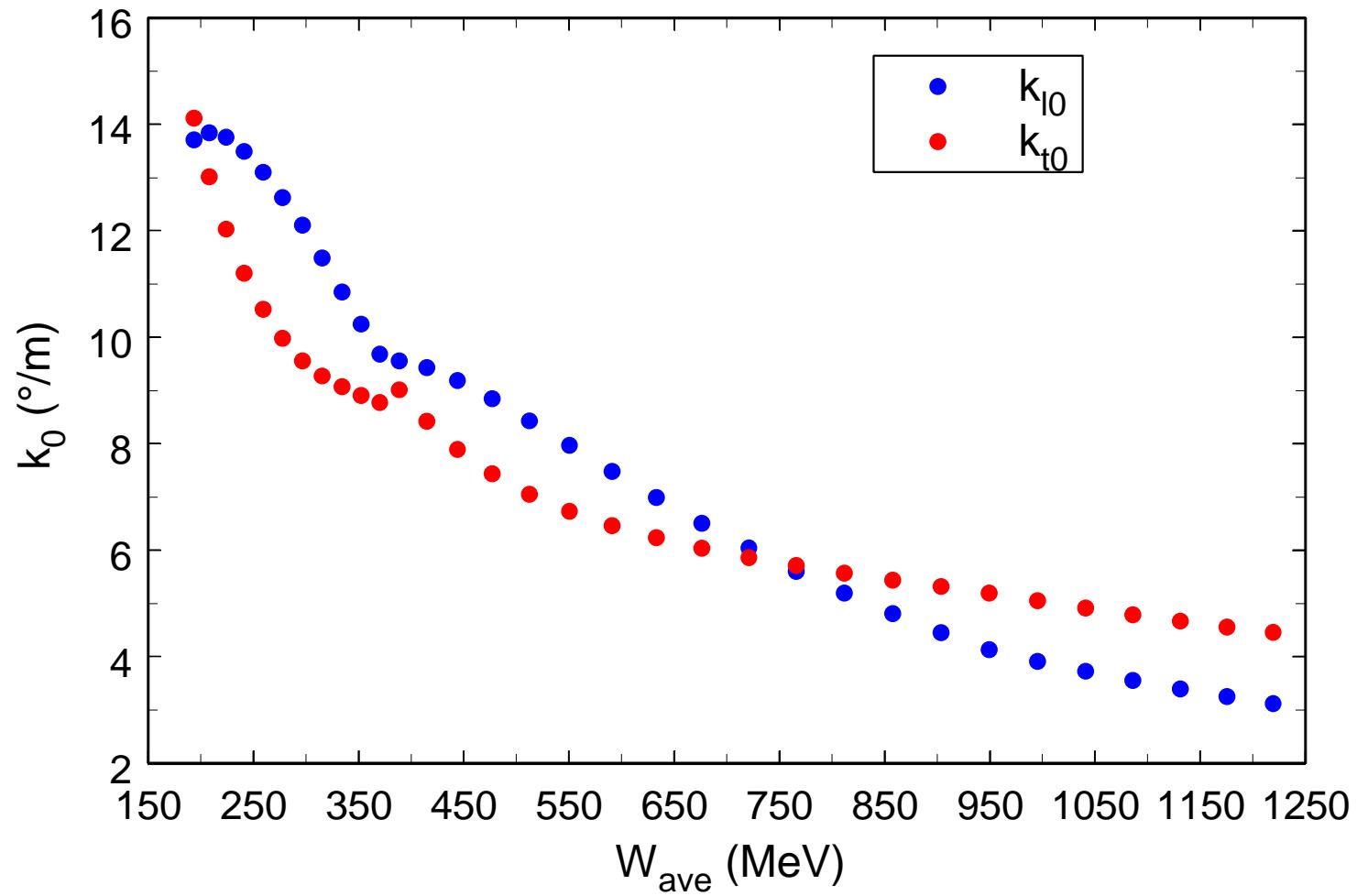
# SRF Linac Design Assumes $E_{\max}=27.5$ MV/m



# Beam Consumes 75% of Available rf Power



# SRF Real-Estate Zero-Current Phase Advance is Smooth & Continuous



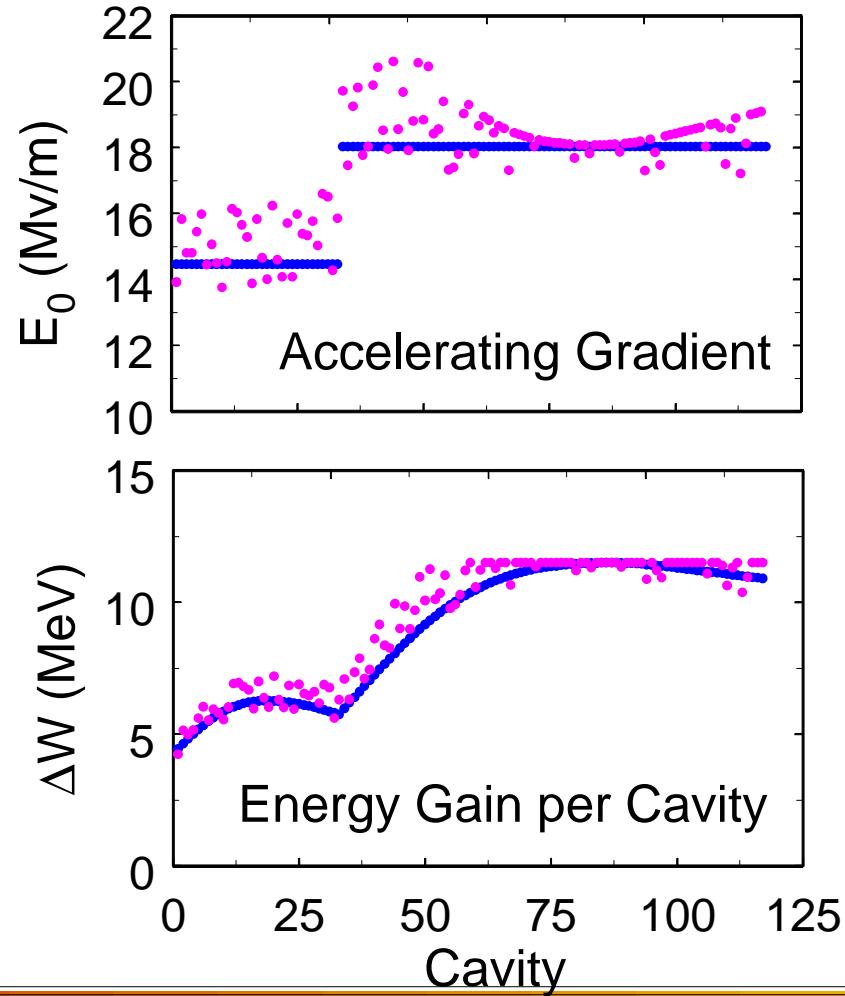
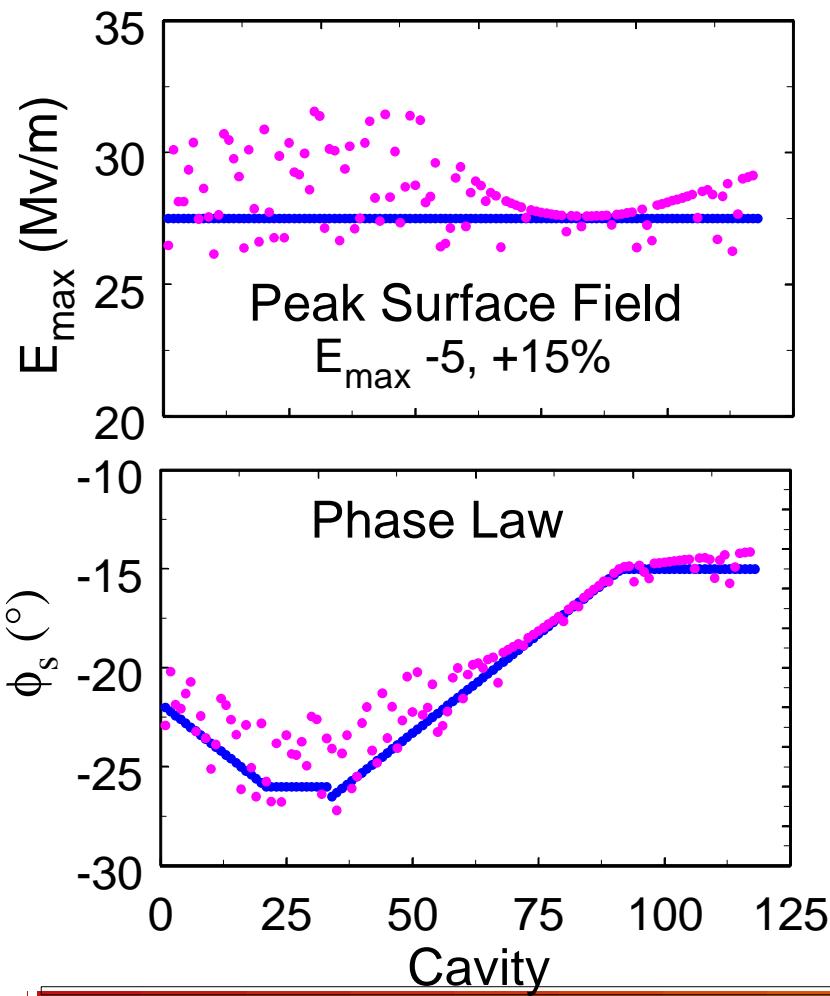
# SRF Phase & Amplitude Set-Points Preserve Longitudinal Dynamics

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- $E_{\max}$  determined at acceptance for each cavity
  - $\langle E_0 \rangle \approx E_{\text{dsn}} \pm 10\%$
- Calibrate cavity field probes
  - using drifting beam to excite cavities
- $E_{0,\text{operating}}$  established for each cavity
- Corresponding  $\phi_{\text{operating}}$  derived for each cavity
  - preserving longitudinal dynamics
  - holding  $k_{0,I}$  constant
    - $k_{0,I}^2 \equiv E_{0,\text{design}} T(\beta) \sin(\phi_{\text{design}} / \beta^3 \gamma^3)$
    - $\phi_{\text{operating}} = \beta^3 \gamma^3 \sin^{-1}(k^2 / E_{0,\text{operating}} T)$

# SRF Operating Example for a Representative Set of Cavities



SNS Linac

Los Alamos

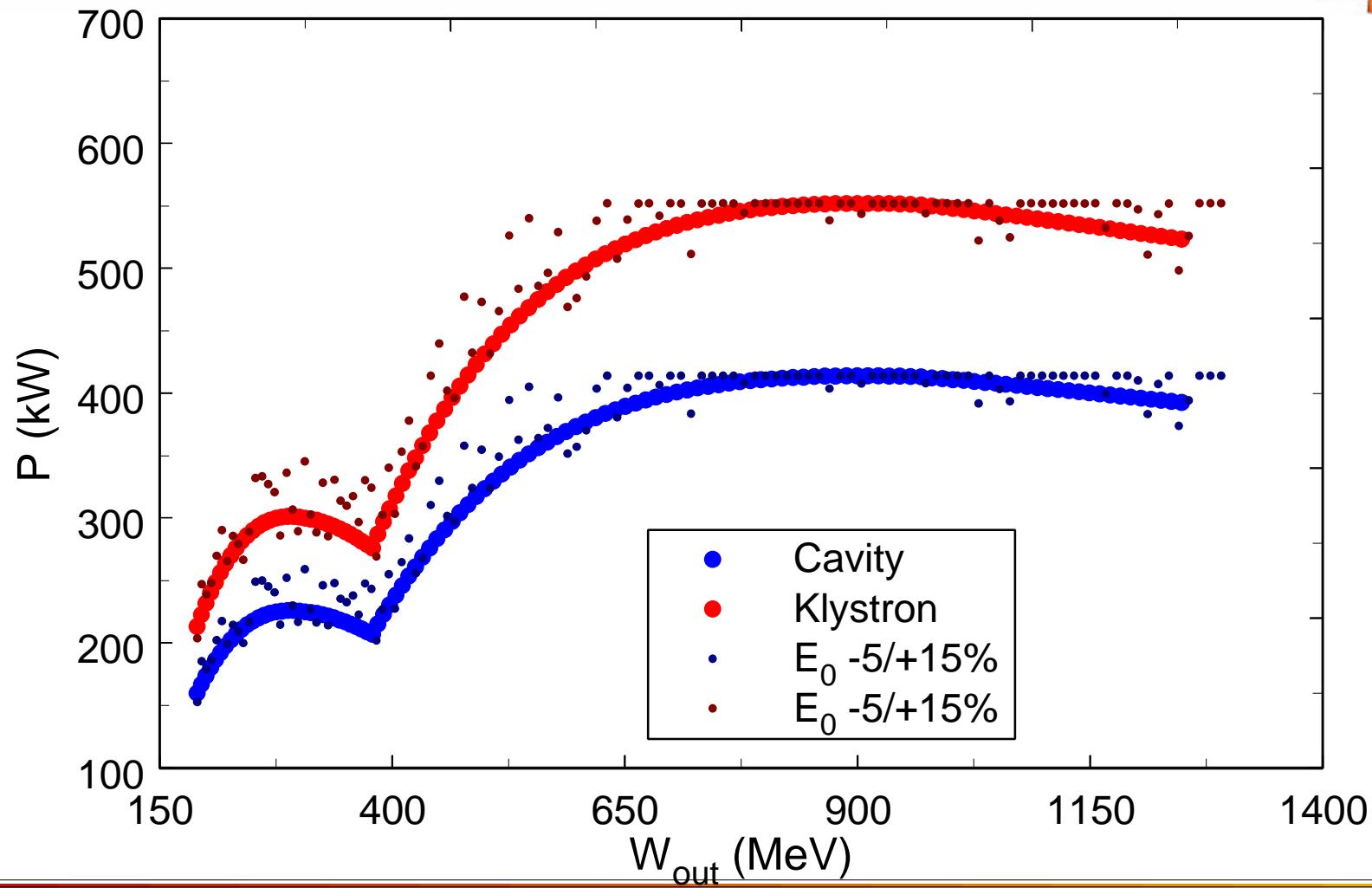
# SRF Linac Will Have 184 Static Field Errors Effecting $W_{\text{final}}$

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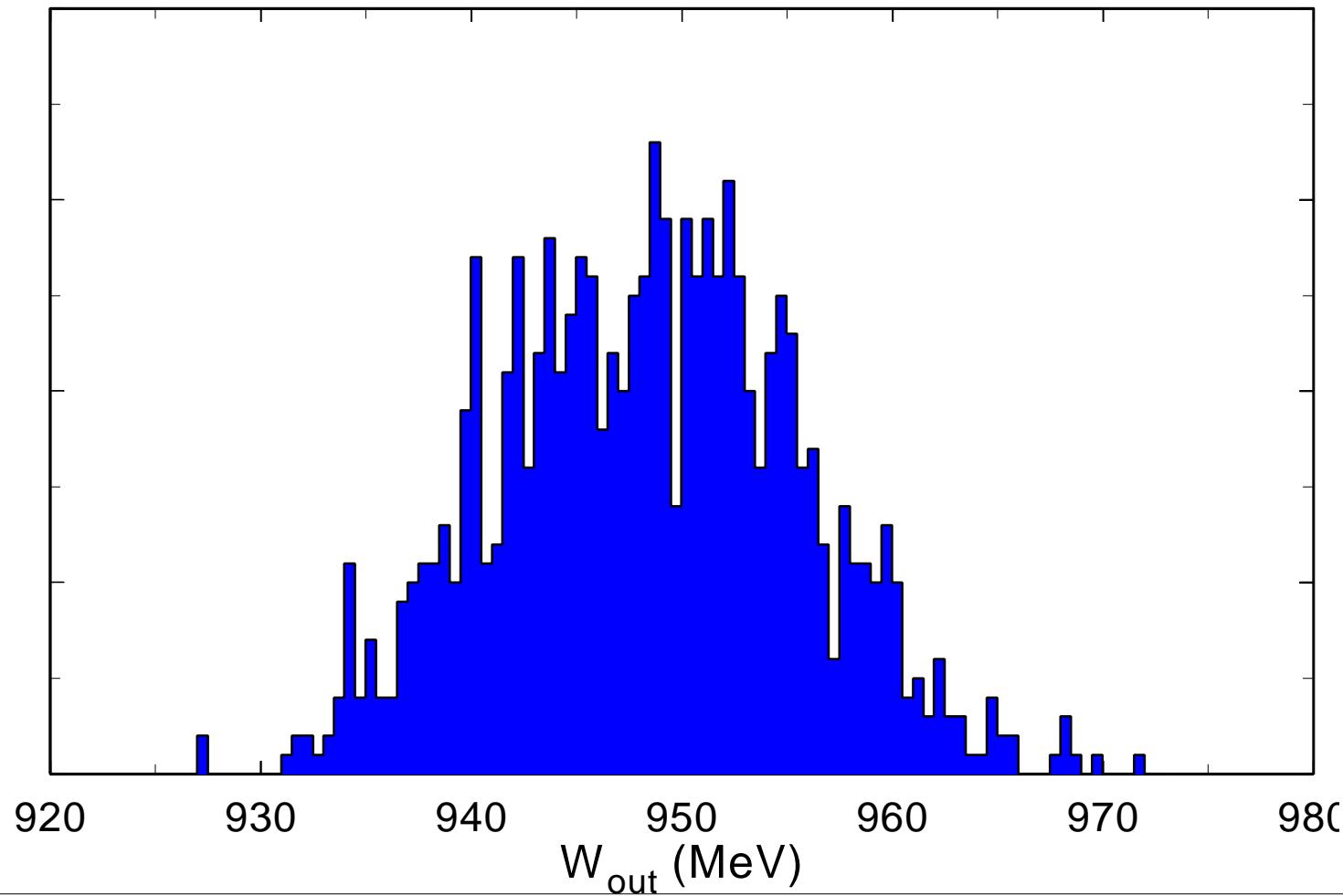
- Design cavity field:  $E_{0,\text{design}}$
- Cavity performance varies:  $E_{0,\text{operating}} = E_{0,\text{design}} \pm 10\% \text{ nom}$
- Field measurement error:  $E_{0,\text{measured}} = E_{0,\text{operating}} \pm 5\% \text{ nom}$
- Design cavity phase:  $\phi_{\text{design}}$
- Phase set-point is derived:  $\phi_{\text{setpoint}} = f(\phi_{\text{design}}, \beta, E_{0,\text{measured}})$
- Phase measurement error:  $\delta\phi = \pm 2^\circ$
- Actual cavity phase:  $\phi_{\text{operating}} = \phi_{\text{setpoint}} + \delta\phi$

# $W_{\text{final}}$ is Limited by $E_{\text{max}}$ & Installed rf Power



# Expected Output Energy

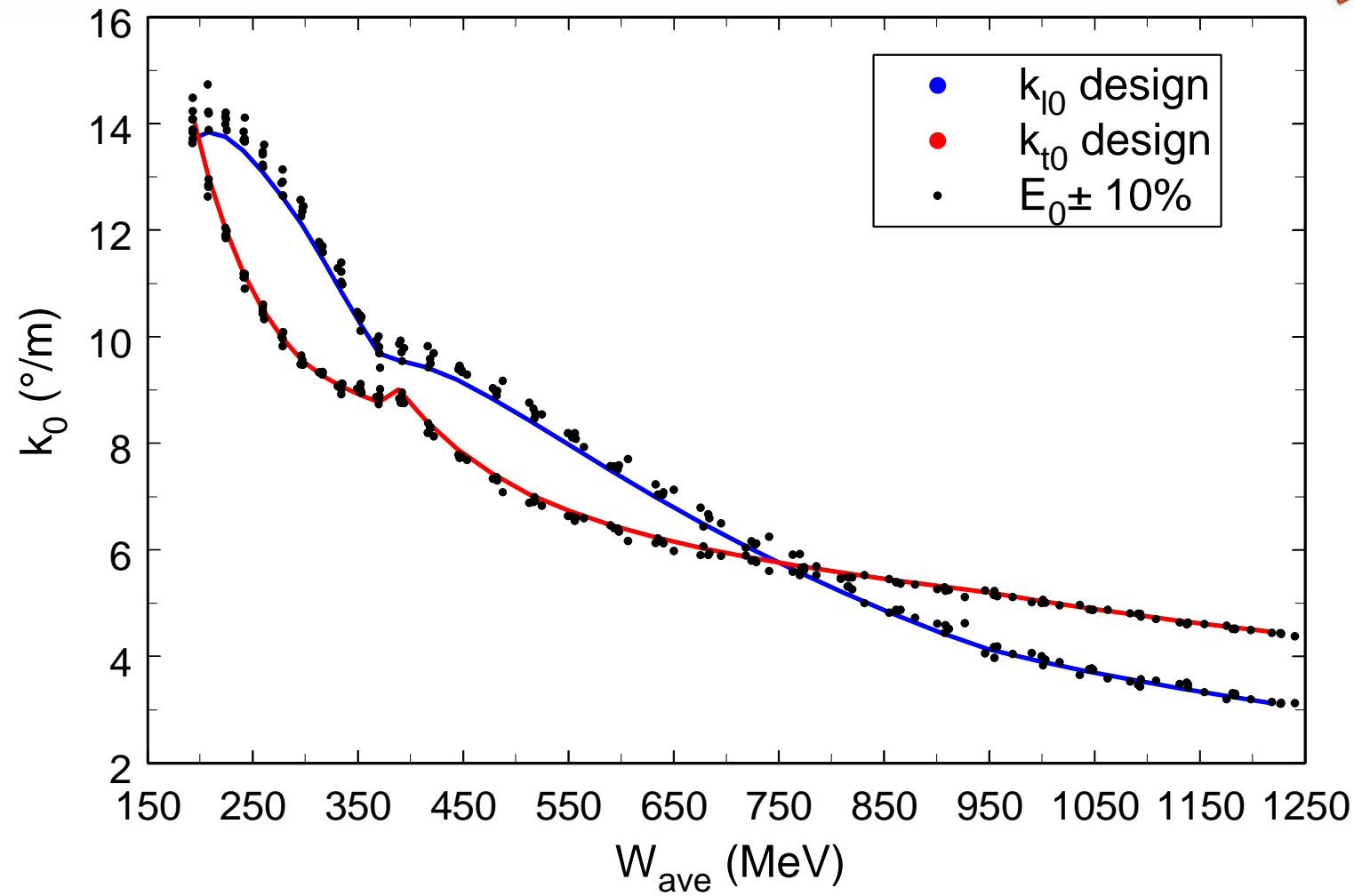
$E_{\max} = 27.5 \text{ MV/m} \pm 10\%$



SNS Linac

Los Alamos

# Tuning Philosophy ( $k_{0,I}=\text{const}$ ) Preserves Beam Dynamics



# End-to-End Beam Dynamics Simulations

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- 4-D “Waterbag” distribution enters the RFQ
- RFQ beam dynamics calculated by:
  - Parmeq: multiparticle space based
  - Toutatis: multiparticle time based
- Linac beam dynamics
  - MEBT, DTL, CCL, SRF & HEBT
  - Parmila is the design code
  - Parmila, Linac & Impact calculate multiparticle beam dynamics
  - LTrace calculates envelope dynamics

# Error Budgets Included in Simulations to Date

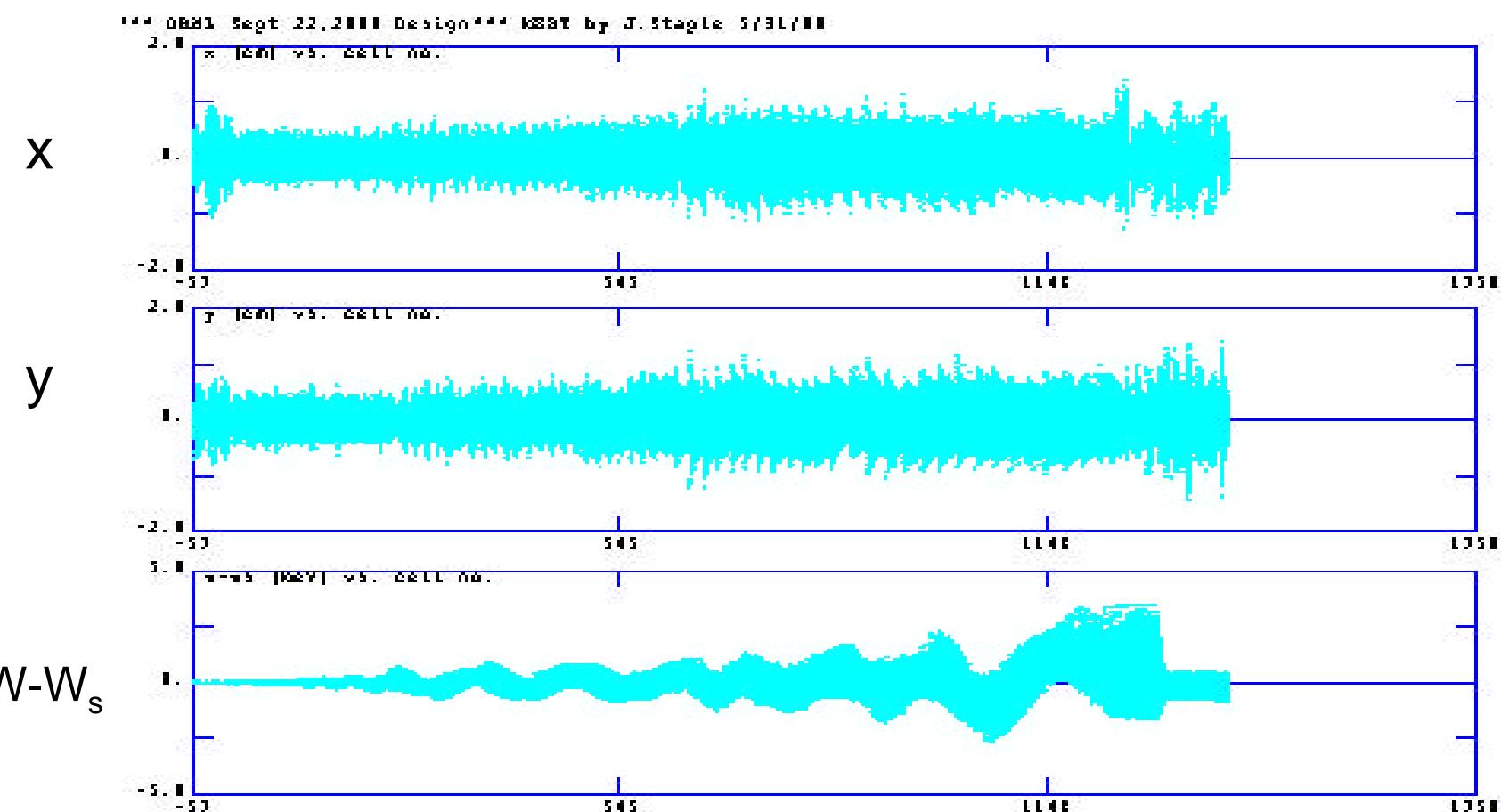
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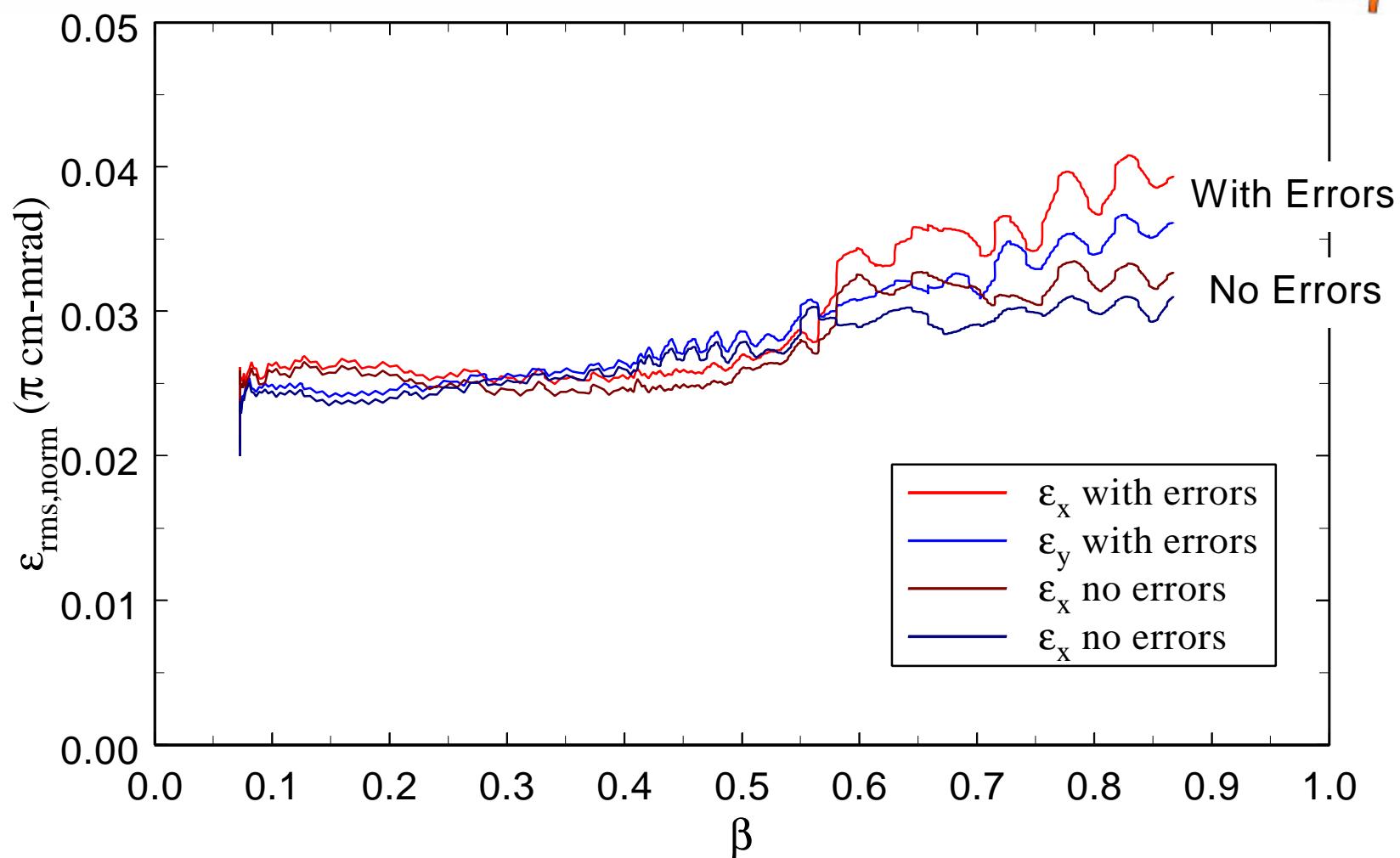
	Units	MEBT	DTL	CCL	SRF
Quad Errors:					
displacement	cm	--	--	--	--
Pitch & yaw	deg	0.57	0.57	0.57	0.57
Roll	deg	0.25	0.29	0.29	0.29
Gradient	%	1.73	0*	0.5	0.5
Cavity Errors, Static:					
Cavity Errors, Dynamic:					
Phase	deg	0.5	0.5	0.5	0.5
Amplitude	%	0.5	0.5	0.5	0.5
Tilt	%	--	0.1	0.	0.

\* Equivalent to 2% sorted.

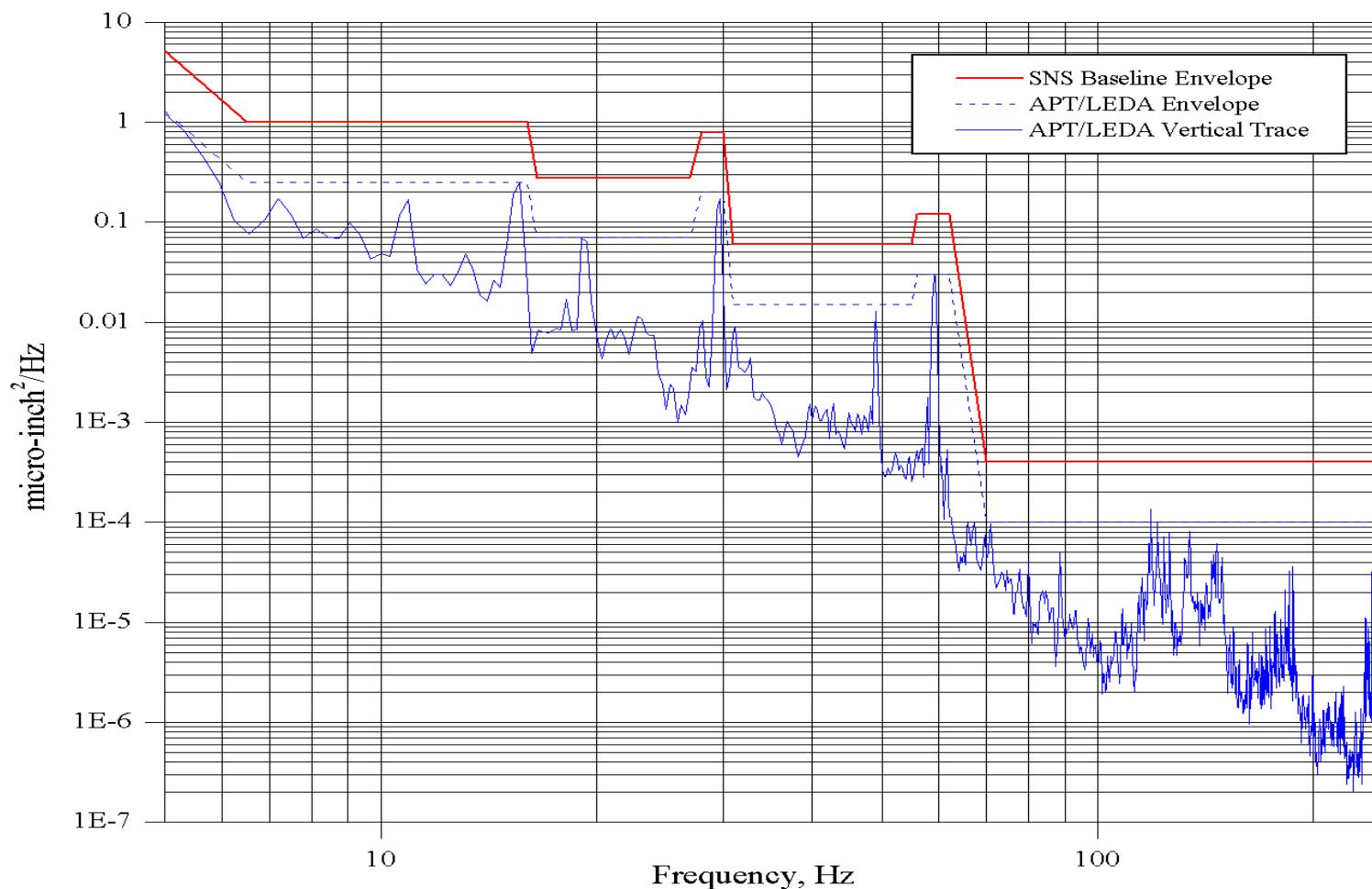
# Beam Profiles for Reference Design With Errors



# rms Emittance Profiles With & Without Errors

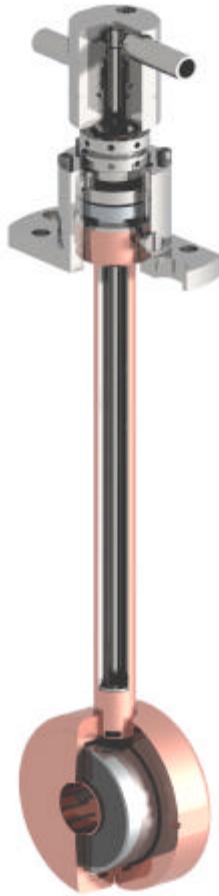


# Expected Vibration Spectrum in the Linac Tunnel



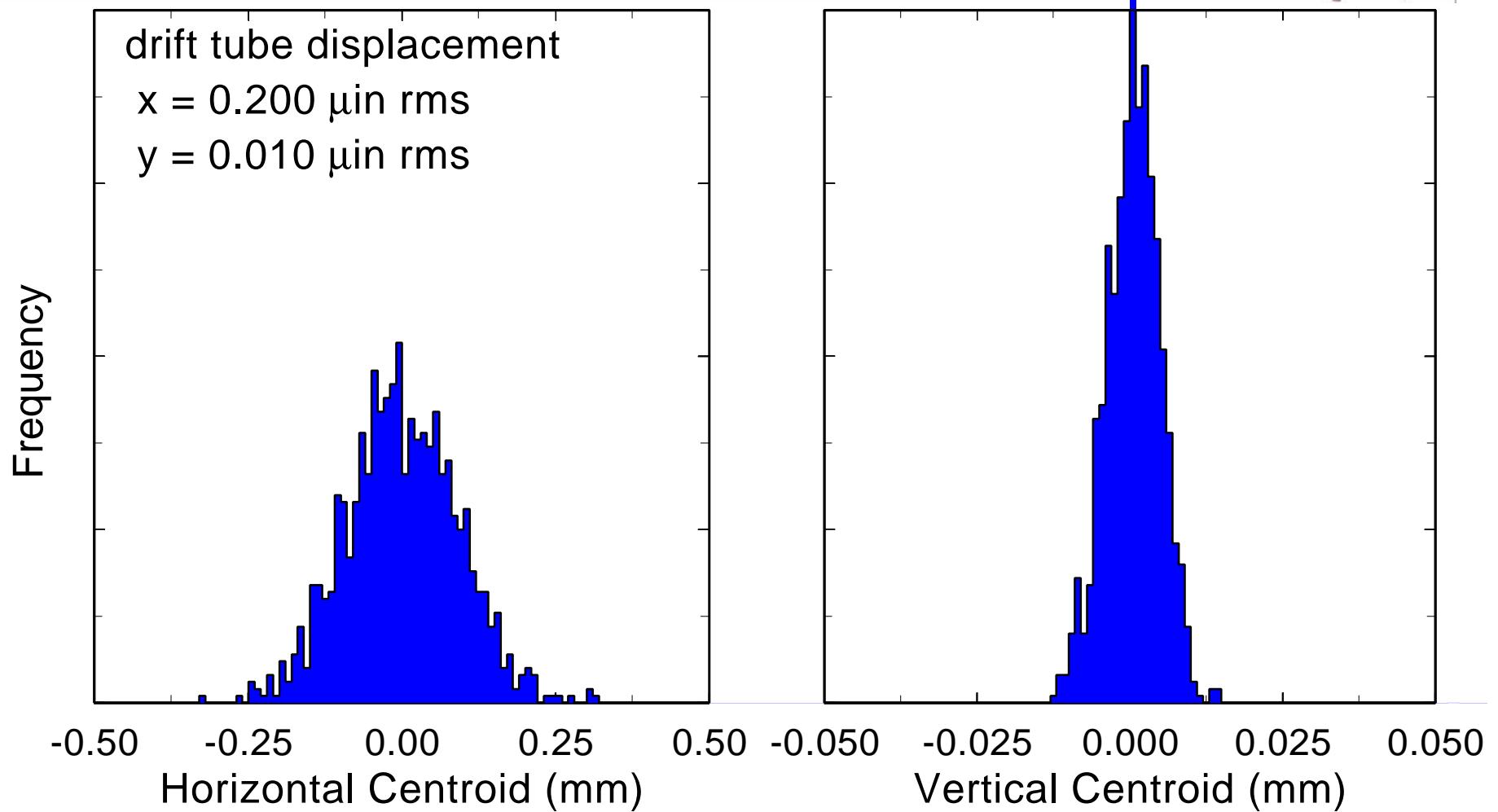
# Vibration Amplitudes are Greatest in Tank 2

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	RMS Displacement		
Drift tube	x axis	y axis	z axis
first	124 $\mu\text{-in}$	24 $\mu\text{-in}$	85 $\mu\text{-in}$
~ middle	200 $\mu\text{-in}$	10 $\mu\text{-in}$	85 $\mu\text{-in}$
end	148 $\mu\text{-in}$	46 $\mu\text{-in}$	86 $\mu\text{-in}$

# Transverse Jitter at the Foil is a Function of Quadrupole Vibrations

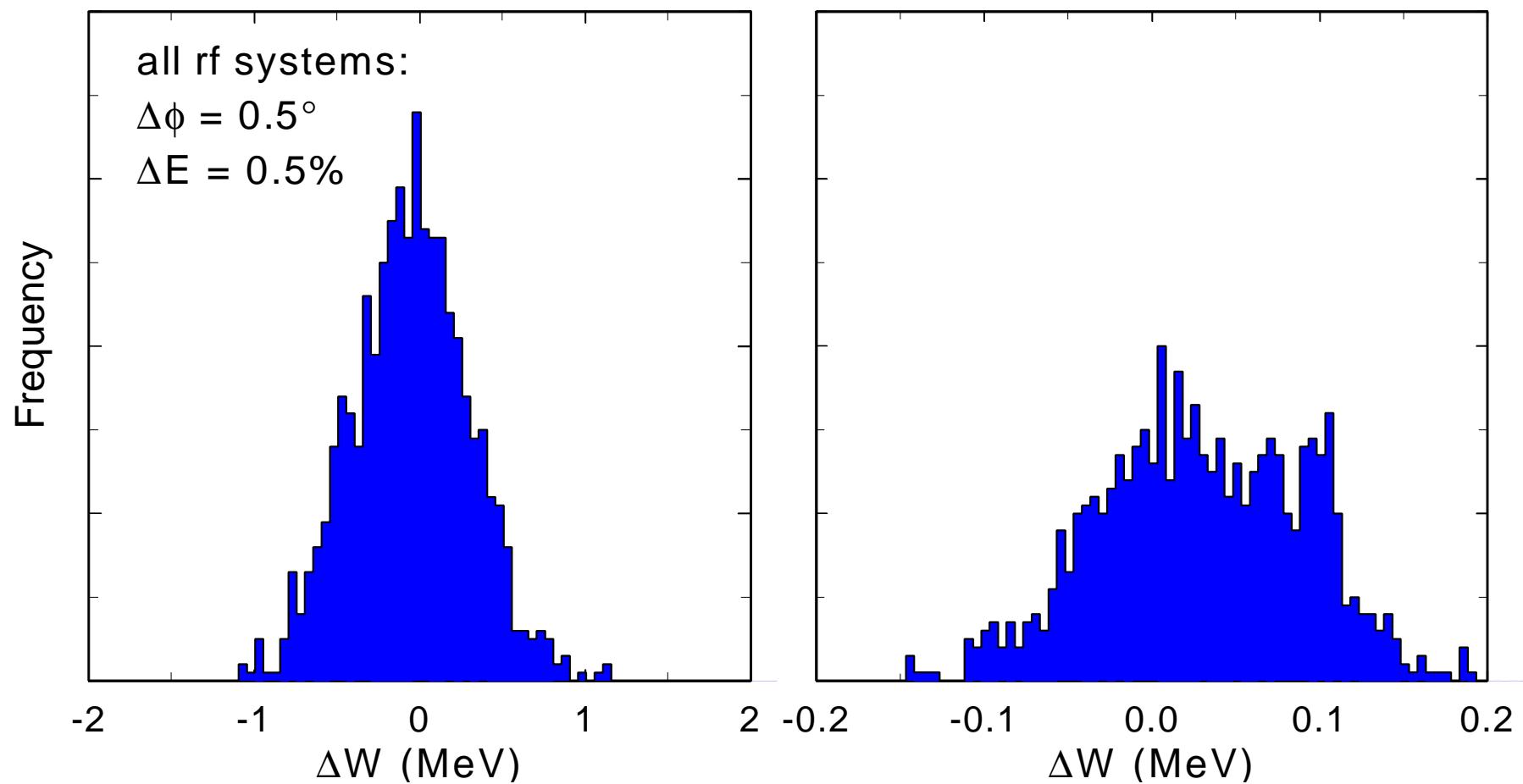


# Energy Jitter is a Function of RF Control Tolerances



Linac Exit

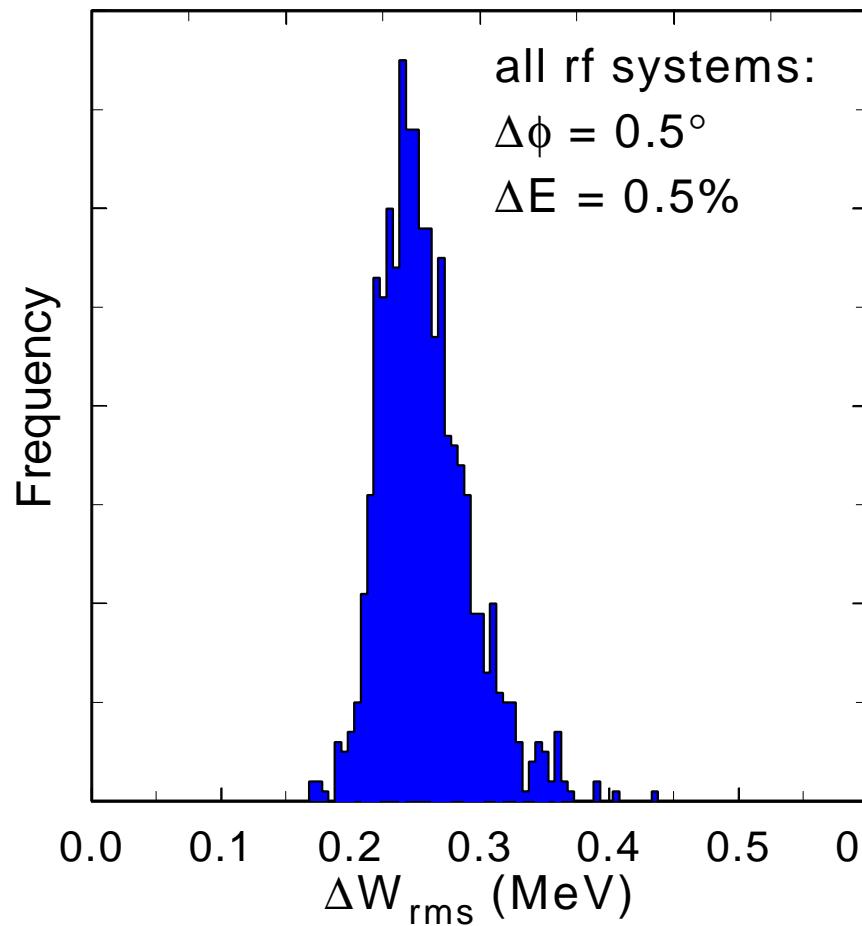
Foil



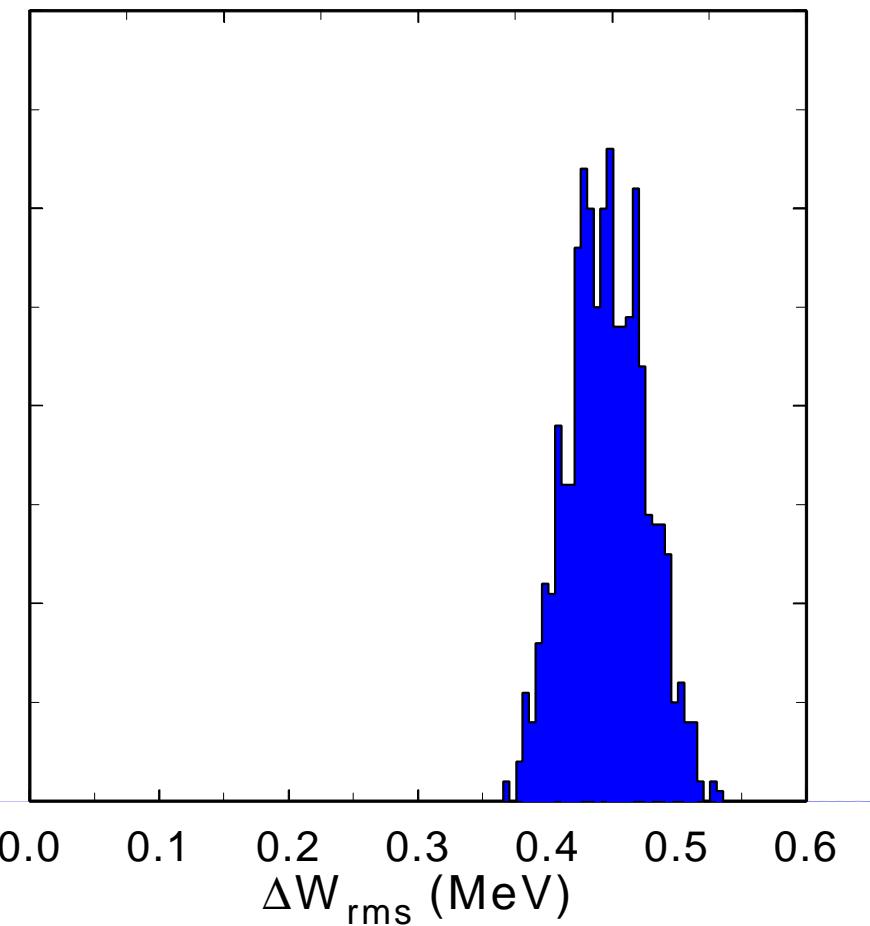
# Energy Spread is a Function of Space Charge & Corrector Voltage



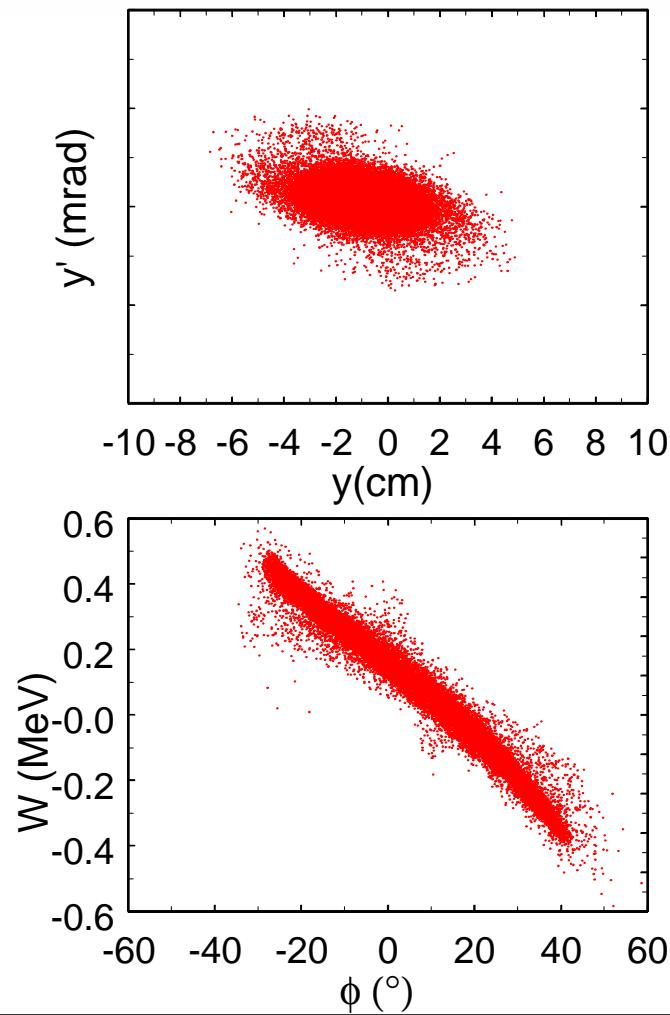
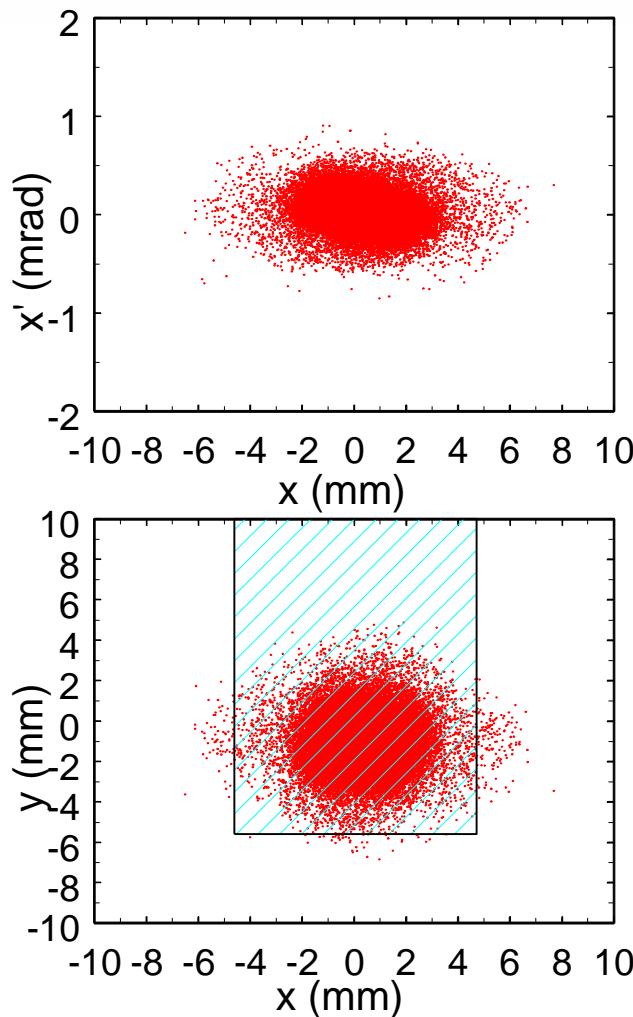
Linac Exit



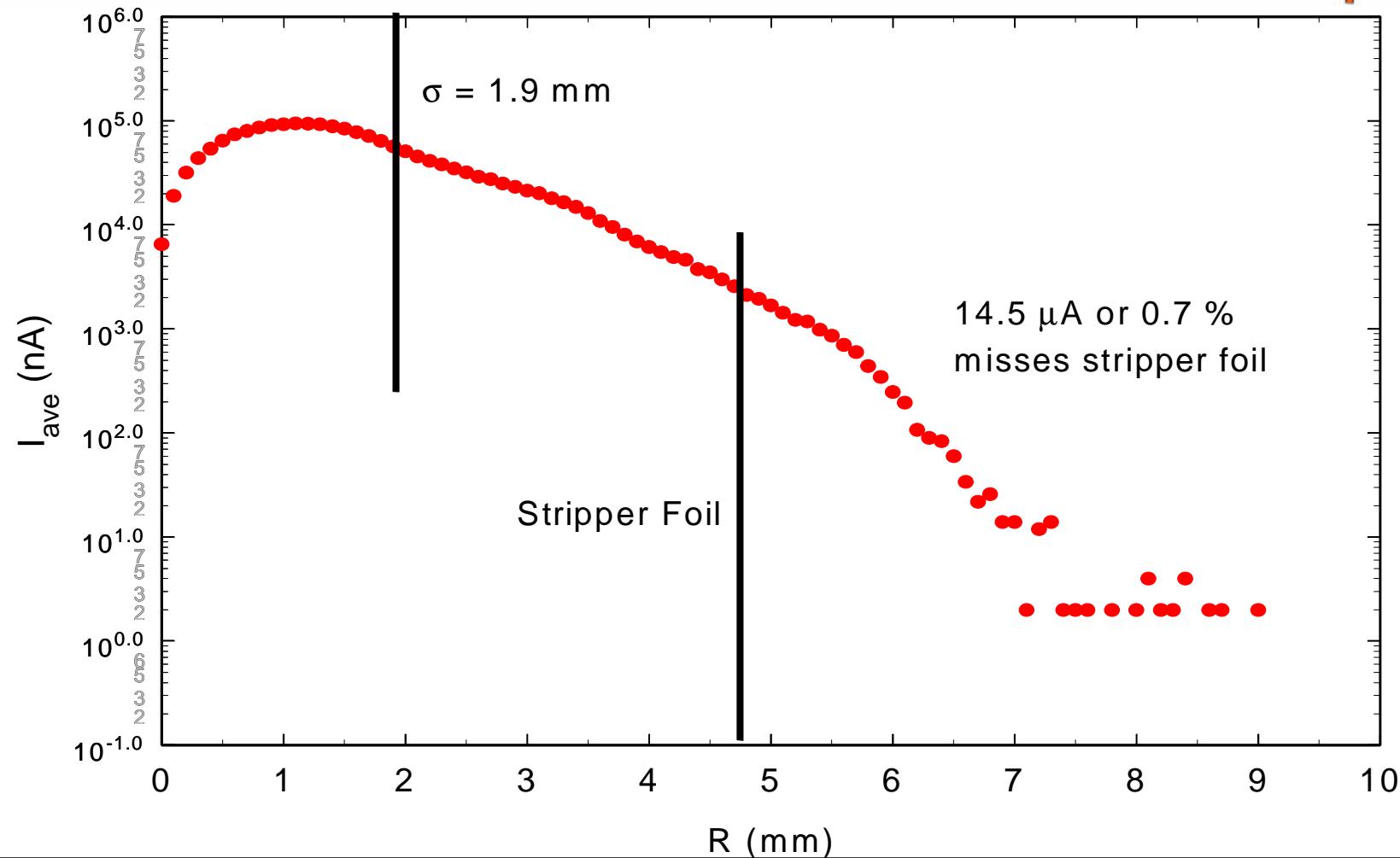
Foil



# Beam Phase-Space Projections at the Foil



# Radial Particle Distribution at the Foil with Errors

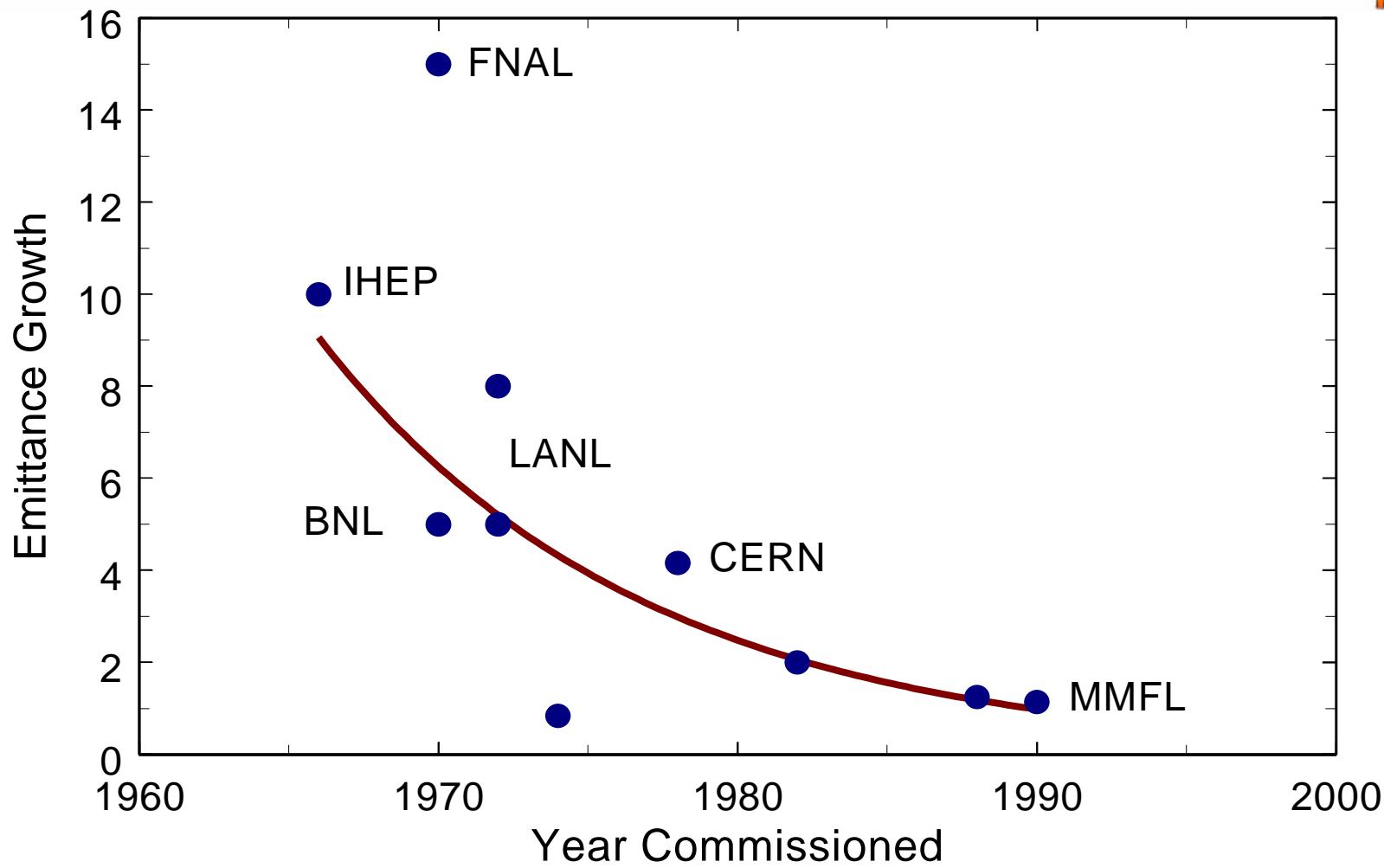


# Emittance Growth is a Function of Many Variables



<b>Linac</b>	<b>W<sub>in</sub></b>	<b>W<sub>out</sub></b>	<b>I<sub>out</sub></b>	<b>e<sub>in</sub></b>	<b>Growth</b>	<b>Vintage</b>
keV MeV						
<b>IHEP</b>	700	103	100	0.2	10	66
<b>FNAL</b>	750	401	50	0.1	15	70/93
<b>BNL</b>	750	200	40	0.4	5	70
<b>LANL</b>	750	800	16	0.093	5	72
				0.09	8	
<b>KEK-40</b>	750	40	18	1.4	0.84	74/85
<b>CERN</b>	750	50	150	1.2	4.16	78
<b>ISIS</b>	665	70	25	--	----	83
<b>Biejing</b>	750	35.5	40	3.0	2	82/85
<b>DESY</b>	750	50	12	0.8	1.25	88
<b>MMFL</b>	750	423	20	0.7	1.14	90

# Emittance Growth Improves With Youth



# Status of Linac Design & Beam Simulation Studies

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- Steering algorithms have been selected
- Dipole & BPM locations identified
- Algorithms incorporated into simulation codes
- Ready to include displacements
- DTL & CCL phase & amplitude set-point algorithms under study
- Code comparisons under study
- Missmatch studies pending
- Full error set pending
- Beam dynamics workshop in Nov.
- HEBT workshop in Dec.